G Model
JECS-11197; No. of Pages 8
ARTICLE IN PRESS
Journal of the European Ceramic Society xxx (2017) xxx–xxx
Contents lists available at www.sciencedirect.com
Journal of the European Ceramic Society
journal homepage: www.elsevier.com/locate/jeurceramsoc

The effects of fiber orientation on failure behaviors of 2D C/SiC torque tube

Hui Zhao, Litong Zhang, Bo Chen*, Zongbei He, Jiaxin Zhang, Yongsheng Liu

Science and Technology on Thermostructure Composite Materials Laboratory, Northwestern Polytechnical University, West Youyi Rd., No. 127, Xi'an, Shaanxi 710072, PR China

ARTICLE INFO

Article history:
Received 5 January 2017
Received in revised form 7 April 2017
Accepted 10 April 2017
Available online xxx

Keywords:
C/SiC torque tube
Fiber orientation
Torque capacity
Failure analysis

ABSTRACT

Different failure behaviors were observed in the 2D C/SiC torque tubes which were fabricated by chemical vapor infiltration (CVI) with different fiber orientations (0°/90° and ±45°). CT test was implemented to characterize the density heterogeneity of the ceramic matrix composite (CMC) torque tubes. With the density value measured by Archimedes drainage method, FEM software was implemented to simulate the stress distribution of the ceramic matrix composite torque tubes and calculate the failure stress. Torsional tests were conducted using special attachments to a universal material test machine. Different torsional behaviors of CMC torque tubes with two different fiber orientations were presented in the stress-strain curves. The fracture morphologies were observed by SEM, and the predominant factors of failure were analyzed. CMC torque tubes with fiber orientation of ±45° have a higher torque capacity and modulus. In failure analysis, we found that ±45° fiber orientation CMC torque tubes have reasonable fracture morphologies.

1. Introduction

Continuous carbon fiber-reinforced silicon carbide matrix composites (C/SiC) have been an attractive material for high-temperature structural applications because of their high specific strength and modulus, high thermal stability, good oxidation-ablation resistance, as well as non-catastrophic failure similar to metals [1–7]. However, many engineering challenges are faced in the application, one of which is addressed in this study.

Ceramic matrix composite torque tube, which needs our special attention, is one of the components in aerospace application. As a result, accurate mechanical properties and failure criteria are critical to the design and use of this structure. As we all know, ceramic matrix composite components are so complicated and especially sensitive to geometry, preform structures and processing conditions. As a result, there is no identical flat coupon to accurately represent the CMC torque tube material. Until now, no failure criterion is proper for CMC materials, not to mention for CMC torque tubes, so it is of great importance to make a detailed investigation into ceramic matrix composite torque tubes. So far, torsional behavior and failure criterions of polymer matrix composite torque tubes have been studied a lot because of the application of drive shafts. An optimization study was carried out to optimize the polymer matrix composite drive shaft in terms of fiber orientation, stacking sequence and number of layers [8]. They concluded that fiber orientation and stacking sequence of the layers of a polymer matrix composite drive shaft strongly affect the torque capacity. Some efforts were devoted to ceramic matrix composite tubes. K. Liao discussed an axial/torsional test method for small-size (about 20 cm in length, 4 cm in diameter) ceramic matrix composite tubular specimens [9]. Robert Hansbrough Carter focused on some large-size CMC torque tubes and calculated the ply-level elastic properties of a CMC material, which is useful to engineering design [10]. However, the investigation with regard to the affection of fiber orientation on large-size CVI CMC torque tubes is rarely reported.

The aim of this paper is to extend the analysis on ceramic matrix composite materials to ceramic matrix composite components. Specifically, we make an investigation into the effect of fiber orientation on failure behavior of 2D C/SiC torque tube. To study mechanical properties and stress distribution of ceramic matrix composite torque tubes, a simplified FEM model was used to analyze failure behaviors. Torsional tests were conducted using special attachments to a universal material test machine to obtain the stress-strain curves and failure strengths. Failure analysis was made according to the SEM morphologies.

* Corresponding author.
E-mail address: vincent@nwpu.edu.cn (B. Chen).

http://dx.doi.org/10.1016/j.jeurceramsoc.2017.04.024
0955-2219/

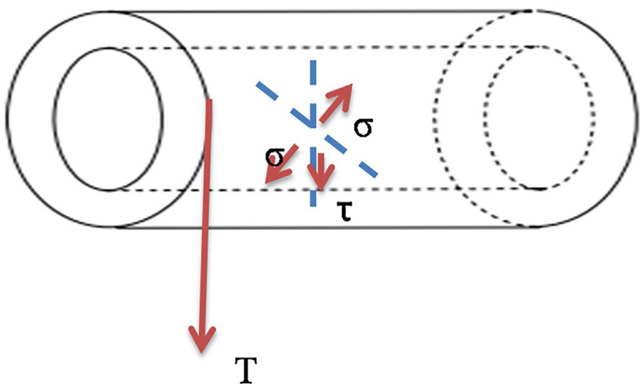

Fig. 1. Schematic of CMC torque tube.

2. Experimental procedure

2.1. Specimens

The plain weave 3 K carbon cloths with different fiber orientations (0°/90° and ±45°) were employed as the reinforcement of the 2D C/SiC torque tubes, a pyrolytic carbon (PyC) layer was deposited on the surface of the carbon fibers as fiber/matrix interface to weaken the interfacial bonding, and then the SiC matrix was introduced by isothermal chemical vapor infiltration (CVI) process [11]. The conditions of CVI process were the same as that described in Ref. [12].

The size of the CMC torque tubes were controlled by mechanical processing after proper time of CVI. The length of the CMC torque tube is 240 mm, the outer diameter is 80 mm and the thickness is 10 mm. Fig. 1 shows the schematic and stress condition under torsional test of the 2D C/SiC torque tube. T, σ and τ is the symbol for torque, maximum normal stress and maximum shearing stress, respectively. The dash line represents the direction of cracks which could be caused by the stress σ and τ. The specimens prepared for the test were divided into two groups, named M10 and M12. M10 is the CMC torque tubes of 0°/90° fiber orientation, and M12 is the CMC torque tubes of ±45° fiber orientation. M10-1, M10-2, M10-3 are in the first group, and M12-1, M12-2 are in the second group.

2.2. Measurements and observations

As a mechanical test specimen, both ends of the CMC torque tube should be reinforced by aluminum-alloy sleeves bonded to the external and internal surface. As a result, we could conduct effective test, the fracture will take place in the gauge section of the CMC torque tube. Four pins were used to fix two ends of the CMC torque tube for the transmission of the torsional moment (Fig. 2). In order to avoid stress intensity, the hole to insert the pins must be elliptical to expand the contact area between the pins and the CMC torque tube, the torque was applied by compression. Three-gauge rosettes (−45°/0°/+45°) were used to depict the strain of the specimen. Four rosettes were placed around the specimen in the middle of the CMC torque tubes, they distributed in every 90° (Fig. 3). Four three-gauge rosettes had the total number of 12 data channels and they collected independently and simultaneously for each loading. Universal material test machine (Instron1850, Instron Corp., MA, USA) was used to apply compression load (Fig. 2). The test was conducted in the placement control mode with a loading rate of 2 mm/min.

Archimedes drainage method was used to obtain the bulk density and porosity of the CMC torque tubes. A finite element method (FEM) was used to investigate the stress distribution of the ceramic matrix composite torque tube. The microstructures and fracture morphologies of specimens were examined by an X-ray computed tomography (CT, BT500, Indintro Co. Ltd., Moscow, Russia) and a scanning electron microscope (JSM6700F, Jeol, Tokyo, Japan).

3. Results and discussion

3.1. Analysis of density/porosity

The mechanical properties of ceramic matrix composite torque tubes are greatly influenced by density, so it is necessary to conduct an investigation. The ceramic matrix composite torque tubes

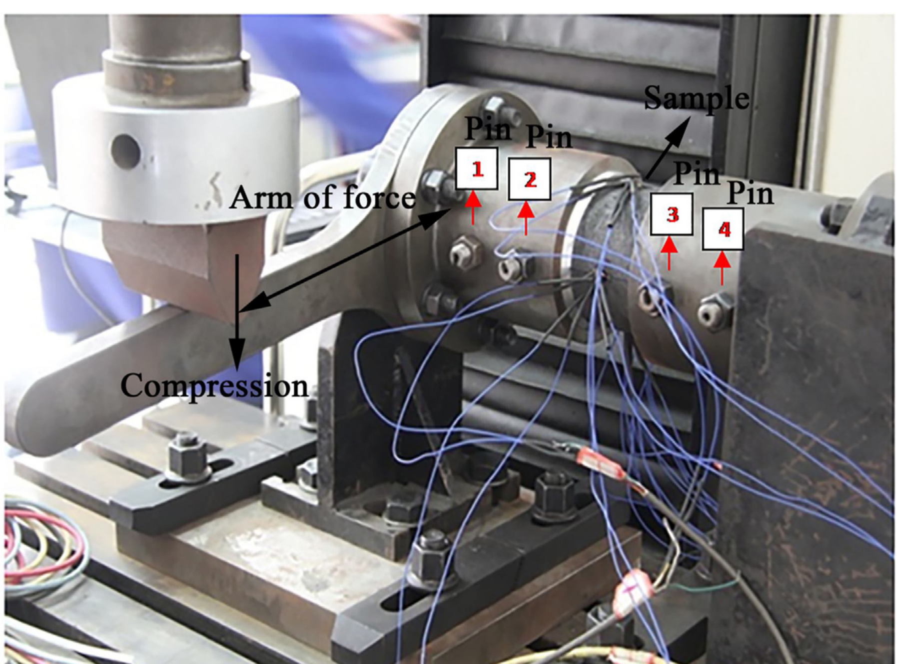

Fig. 2. Experiment graph of test equipment.

Please cite this article in press as: H. Zhao, et al., The effects of fiber orientation on failure behaviors of 2D C/SiC torque tube, *J Eur Ceram Soc* (2017), http://dx.doi.org/10.1016/j.jeurceramsoc.2017.04.024